Characterizing Model Errors through Comparison with Observations

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Proposal:

- Fitting observations over an extended time range by adjusting parameterizations of likely model errors is a possible way of characterizing model error and improving models
- Complementary to the usual analysis of forecast errors and other methods
- Implements "weak constraints" with physics

Motivation: coupled modeling (e.g.)

Ultra High Resolution Global Climate Simulation to Explore and Quantify Predictive Skill for Climate Means, Variability and Extremes

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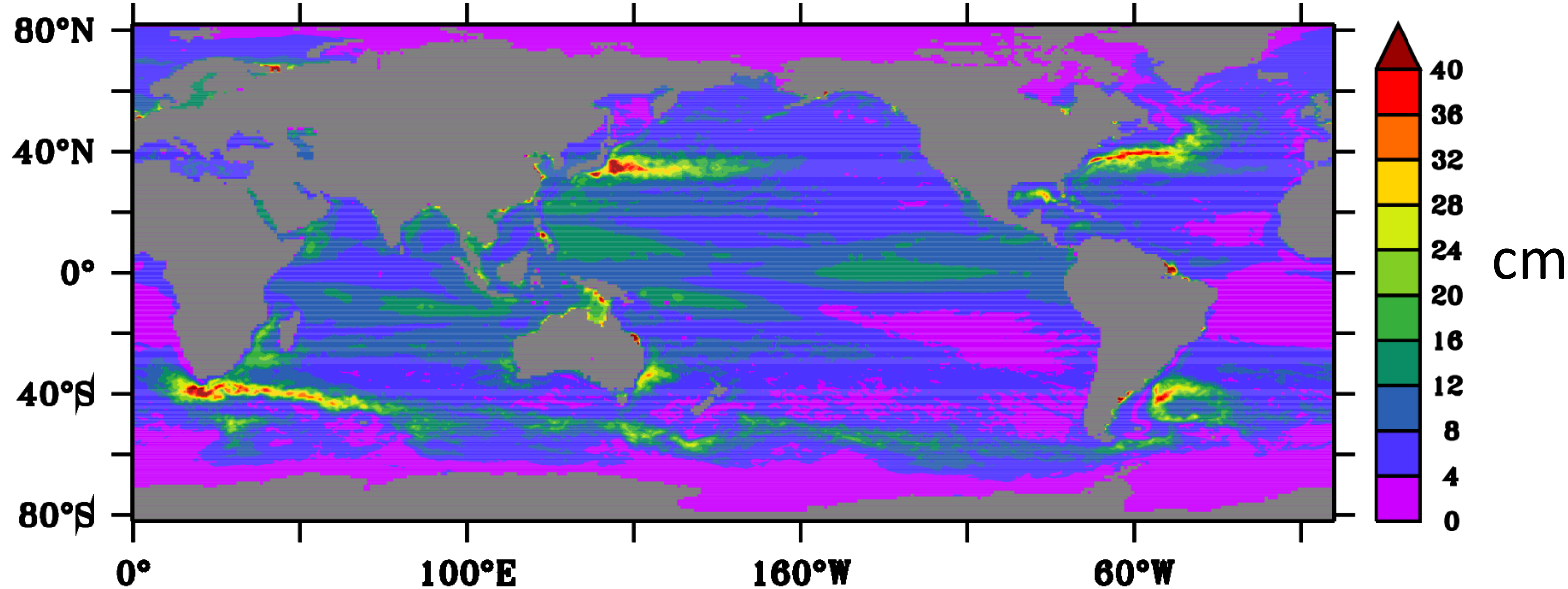
Coupled Modeling Project Goals

- Test hypothesis that higher resolution models are needed
  - To include explicit simulation of non-linear phenomena and interactions on the small scale that have feedbacks on large scale climate features
  - To provide accurate and explicit simulations of local to regional scale phenomena, including low-probability, high-impact hydrological events

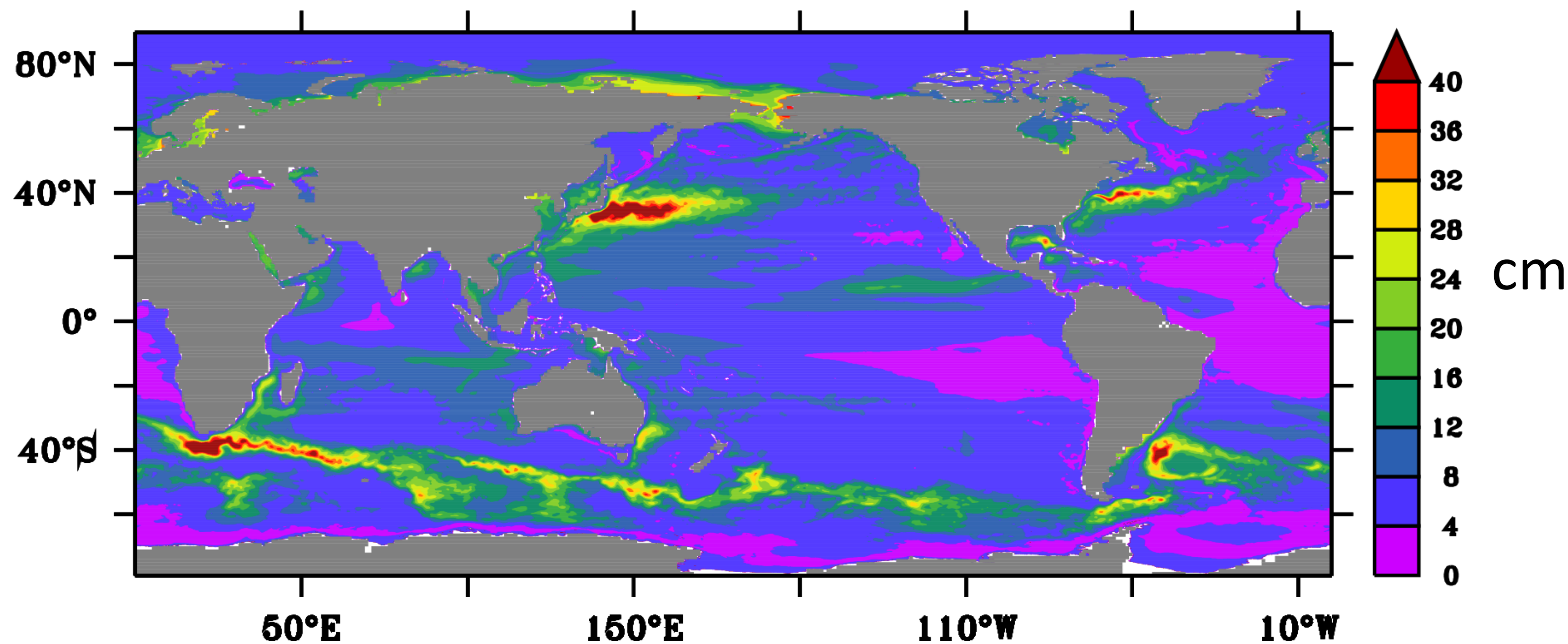
Experimental Plan and Status

- Initial state exploration, sensitivity
  - 0.1° forced POP-CICE: 40 years. Use for initialization of high resolution preindustrial and present day transient simulations. Completed.
- T341 Experiment:
  - T341 /0.1° POP-CICE preindustrial (CAM4 physics): 50 years. Completed.
- CAM-SE Experiments
  - 0.25°/0.1° POP-CICE preindustrial (CAM4 physics): evaluated against T341.
  - CAM-SE used for all future work, including ensemble of late 20th century/ early 21st century transients
- T85 Comparative Experiments: completed.
  - T85/x1° POP-CICE preindustrial for comparison to “standard” CCSM 4 release
  - Ensemble of late late 20th century/ early 21st century transients to test initialization strategy.

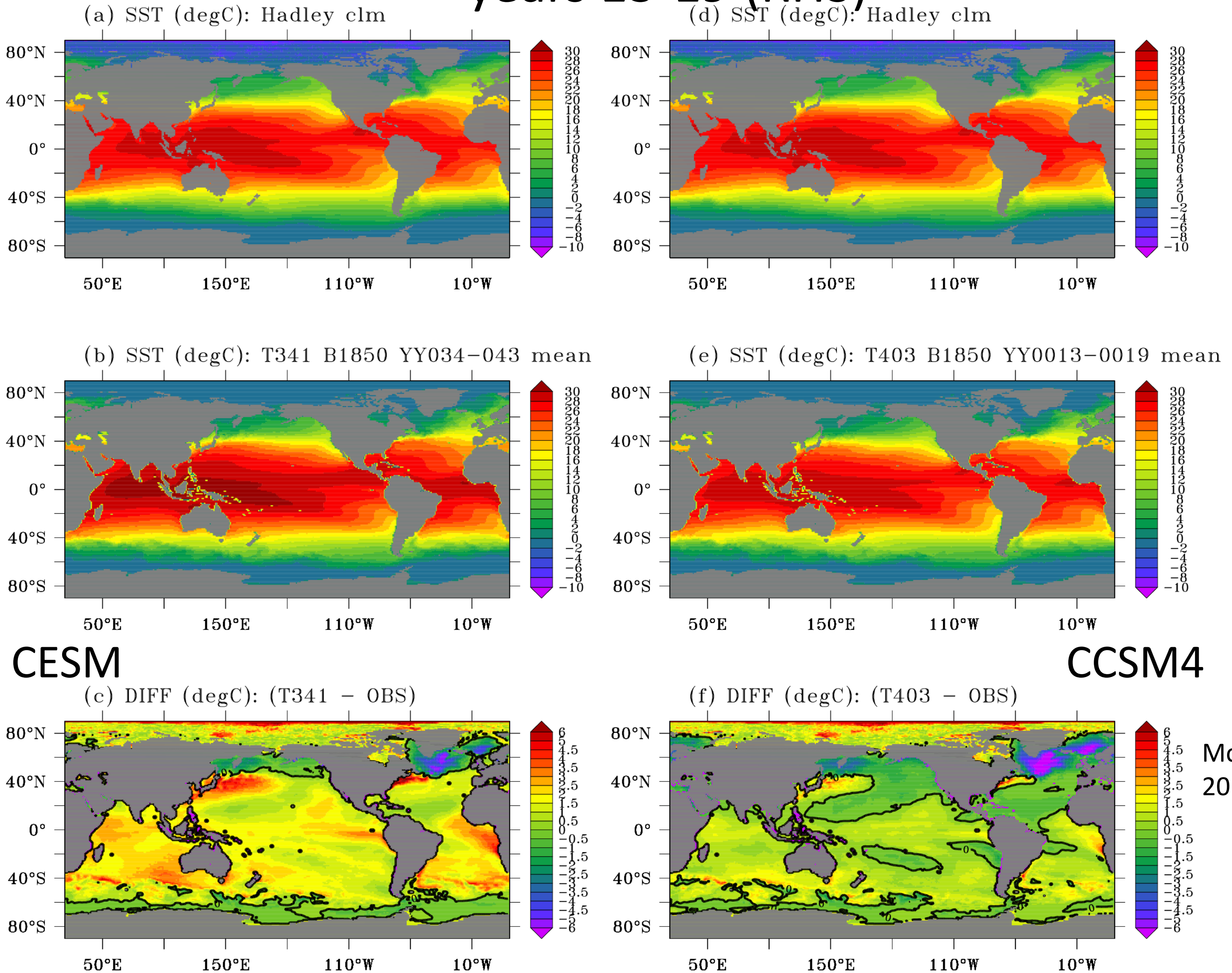


RMS SSHA (cm) from AVISO (upper) and 7-daily SSHA from T341 (lower)

(b) B1850 T341 RMS SSH (cm)



SST: Hadley PI climatology, T341 years 34-43 (LHS), Atlas for years 13-19 (RHS)



McClean et al. 2011, OM

Problem: diagnosing model error

- How to trace back biases or drifts to the need for better resolution or parameterizations?

Example: Tropical Pacific and Kz

- Adjust vertical diffusivity (Kz) (aka Kv) to improve the fit of an ocean GCM to observations for 2007 in the Tropical Pacific using 4DVAR with Kv added to the set of controls.
- Stammer (2005) adjusted horizontal and vertical diffusivity and viscosity in a global 2 degree OGCM
- Liu, Koehl, and Stammer (2012) adjusted a number of model parameters in a global 1 degree OGCM

Stammer (2005) adjusted horizontal and vertical diffusivity and viscosity in a global 2 degree OGCM to fit 9 years of observations

Adjusting Internal Model Errors through Ocean State Estimation

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ABSTRACT

Oceanic state estimation is a powerful tool to estimate internal model parameters simultaneously with the model's initial conditions and surface forcing field that jointly would bring a model into consistency with time-varying large-scale ocean observations. Here an attempt to estimate geographically varying fields of horizontal and vertical viscosity and diffusivity within a 9-yr-long estimation procedure is presented. The estimated coefficients are highly efficient in preserving watermass characteristics and frontal structures by reducing the model temperature and salinity drift, especially around the Southern Ocean. The estimated mean circulation results in stronger transports of western boundary currents and of the Antarctic Circumpolar Current. Moreover, an increase of about 10% in the strength of the meridional overturning circulation and in the poleward heat transport can be found. Estimated changes in the horizontal mixing coefficients seem to agree with the notion that diapycnal mixing is superfically high with Laplacian mixing formulations, especially close to frontal structures in the ocean. In comparison with adjustments in tracer diffusivities (vertically and horizontally), adjustments of viscosity coefficients are fairly minor outside lateral boundary regions, suggesting that state estimation attempts might be most successful in providing enhanced insight into tracer mixing.

Adjoint-Based Estimation of Eddy-Induced Tracer Mixing Parameters in the Global Ocean

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(Manuscript received 30 August 2011, in final form 5 March 2012)

ABSTRACT

Using the German Estimating the Circulation and Climate of the Ocean (GECCO) synthesis framework, four separate eddy tracer mixing coefficients are adjusted jointly with external forcing fields, such as to reduce a global misfit between the model simulations and ocean observations over a single 10-yr period and weighted by uncertainties. The suite of the adjusted eddy tracer mixing coefficients includes the vertical diffusivity k_z, the along-isopycnal surface diffusivity k_{redi}, the isopycnal layer thickness diffusivity k_{gm}, and the along-isothickness advection coefficient k_{gmskew}. Large and geographically varying adjustments are found in all four parameters, which all together lead to an additional 10% reduction of the total cost function, as compared to using only surface flux parameters. However, their relative contribution to the cost reduction varies from 1% to 50% among the four coefficients, with the adjusted k_{gm} contributing most. Regionally, the estimated k_{gm} ranges from less than −800 to about 2500 $m^2 s^{-1}$. Largest adjustments in k_{gm} reside in the vicinity of large isopycnal slopes and support a mixing length hypothesis; they also likewise support the hypothesis of a critical layer enhancement and high potential density gradient suppression. In a few occasions, resulting negative net k_{gm} values can be found in the core of main currents, suggesting the potential for an inverse energy cascade transfer there. Large adjustments of k_{redi} and k_{gmskew} are found in the vicinity of isopycnal slopes. The adjustments of k_z in the tropical thermoclines suggest deficiencies of the mixed layer parameterization.

Estimated Kz : Zonal mean. Shows "Tripole" at equator

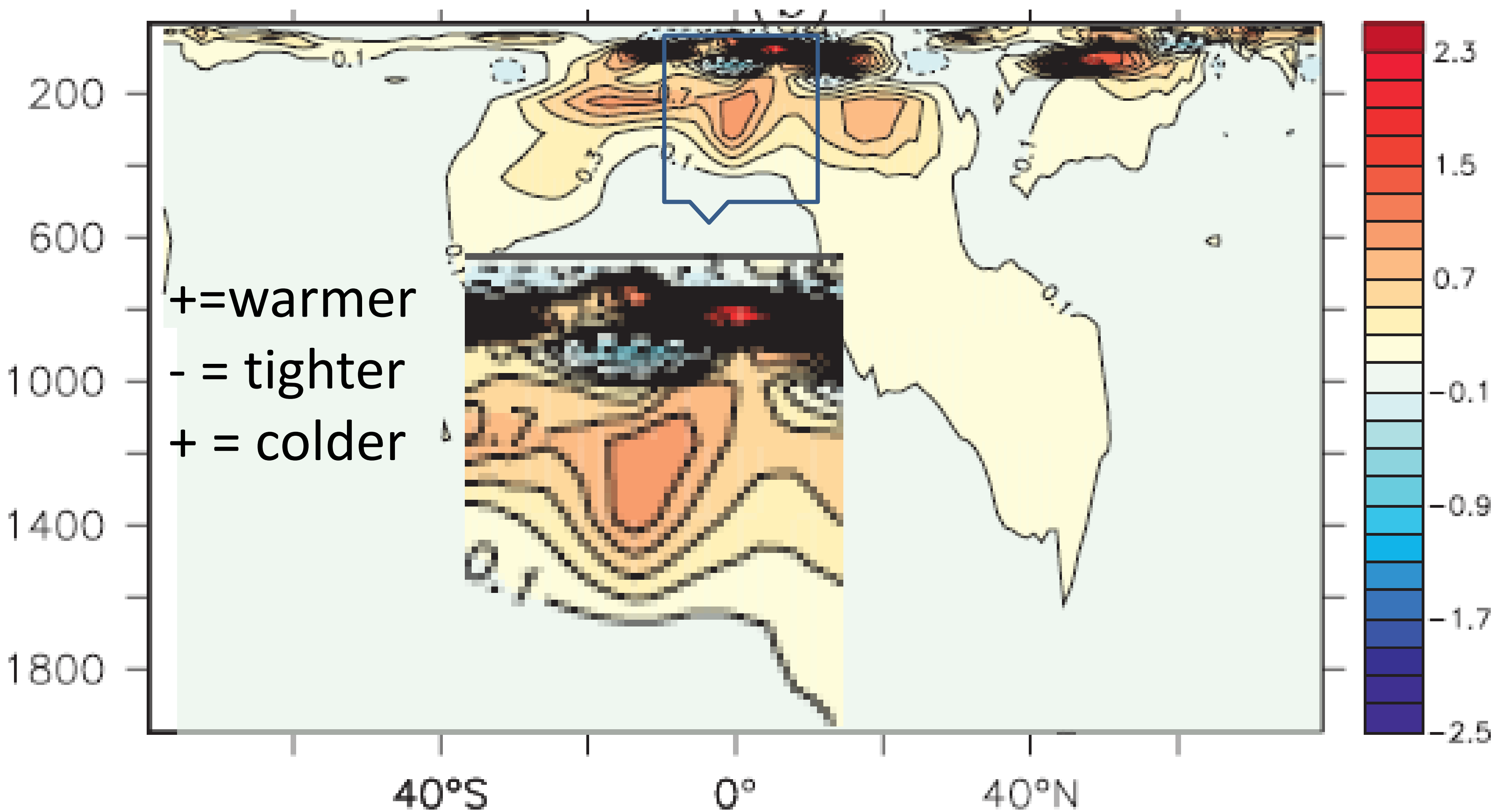

FIG. 13. (a) The δk_z (10^{-6} m^2 s^{-1}) at 310 m and (b) its zonal mean.

Kz Tripole should sharpen thermocline

- These adjustments make a low-resolution climate model fit the data better, but they do not necessarily produce a better estimate of the true eddy parameters
- Tested in a higher-resolution model run at SIO
- Related work: Charles Jackson, UTA doing Bayesian inversion for KPP parameters in tropical Pacific MITgcm (in process)

SIO/UHH/UH project: try in higher resolution

Estimating Ocean Mixing and Form Drag in the tropical Pacific

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Bruce Cornuelle
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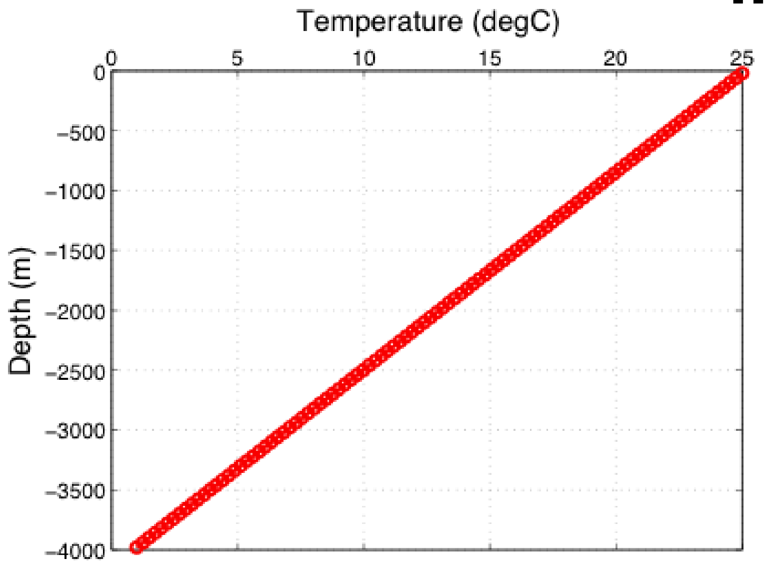
Jay McCreary, Ryo Furue, Peter Muller

SIO, UH/IPRC, UH/SOEST, and UHH

Goals

- Understand how adjusting mixing parameters changes the flow
- Fit the model to observations using all usual controls plus mixing terms
- Explore a useful form of model error
- Use “Generalized Process Experiments” to make estimates of the mixing in the tropical Pacific

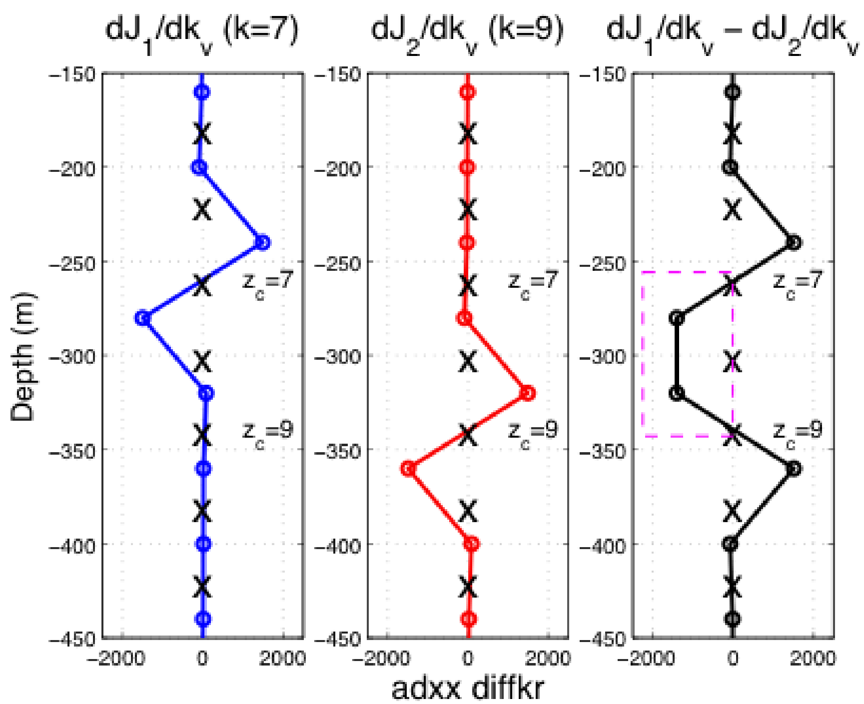
Example: Adjoint in simple box model



Start with a horizontally uniform linear vertical temperature gradient. Ask how the temperature at chosen depths is sensitive to changes in Kz

J = cost function (temperature)

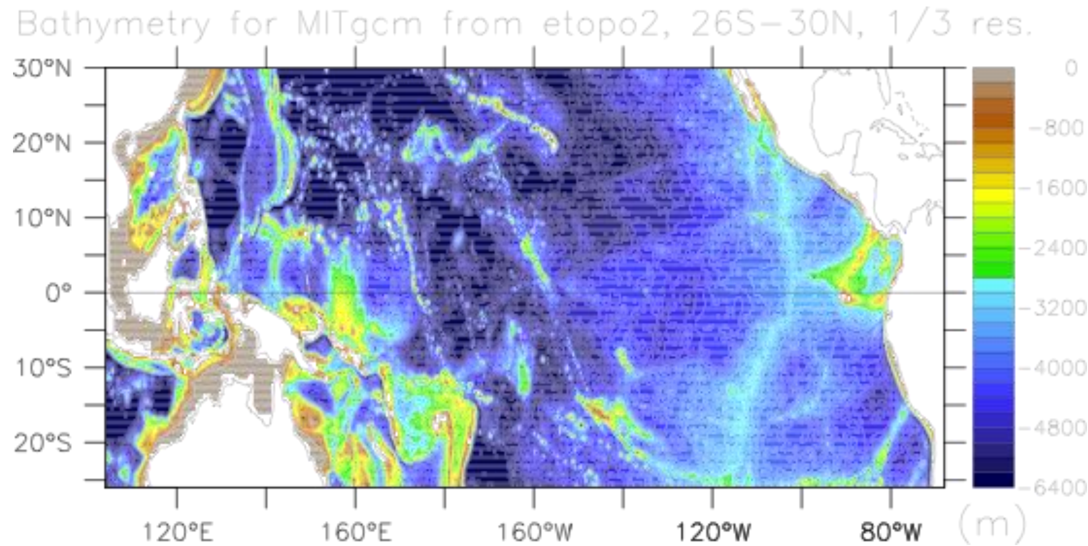
T flux = Kv*dT/dz; DT/dt = d/dz(T flux)



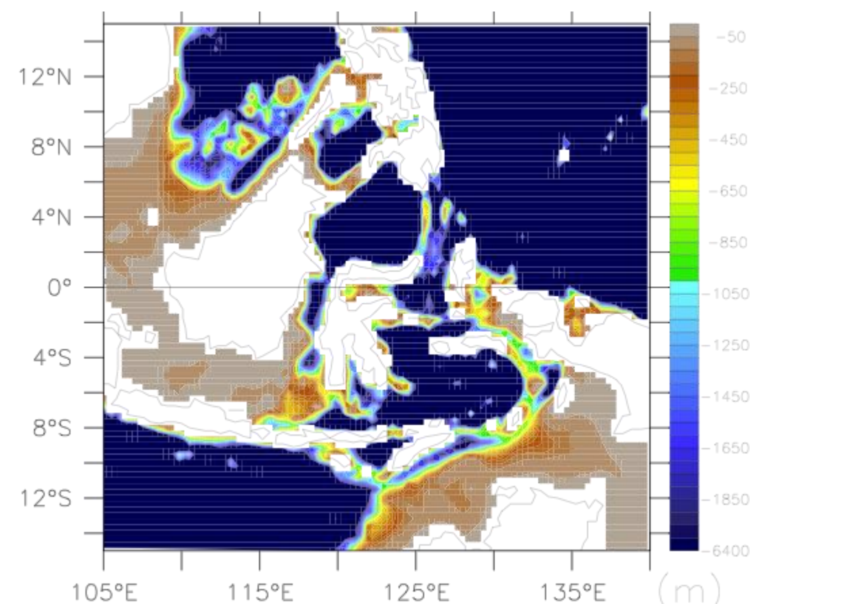
The neg. (pos.) values indicate that a decrease (increase) in K_z will act to increase (decrease) $T_{(k=9)}$-$T_{(k=7)}$, i.e.: to sharpen (weaken) the thermocline.

TROPICAL PACIFIC MODEL

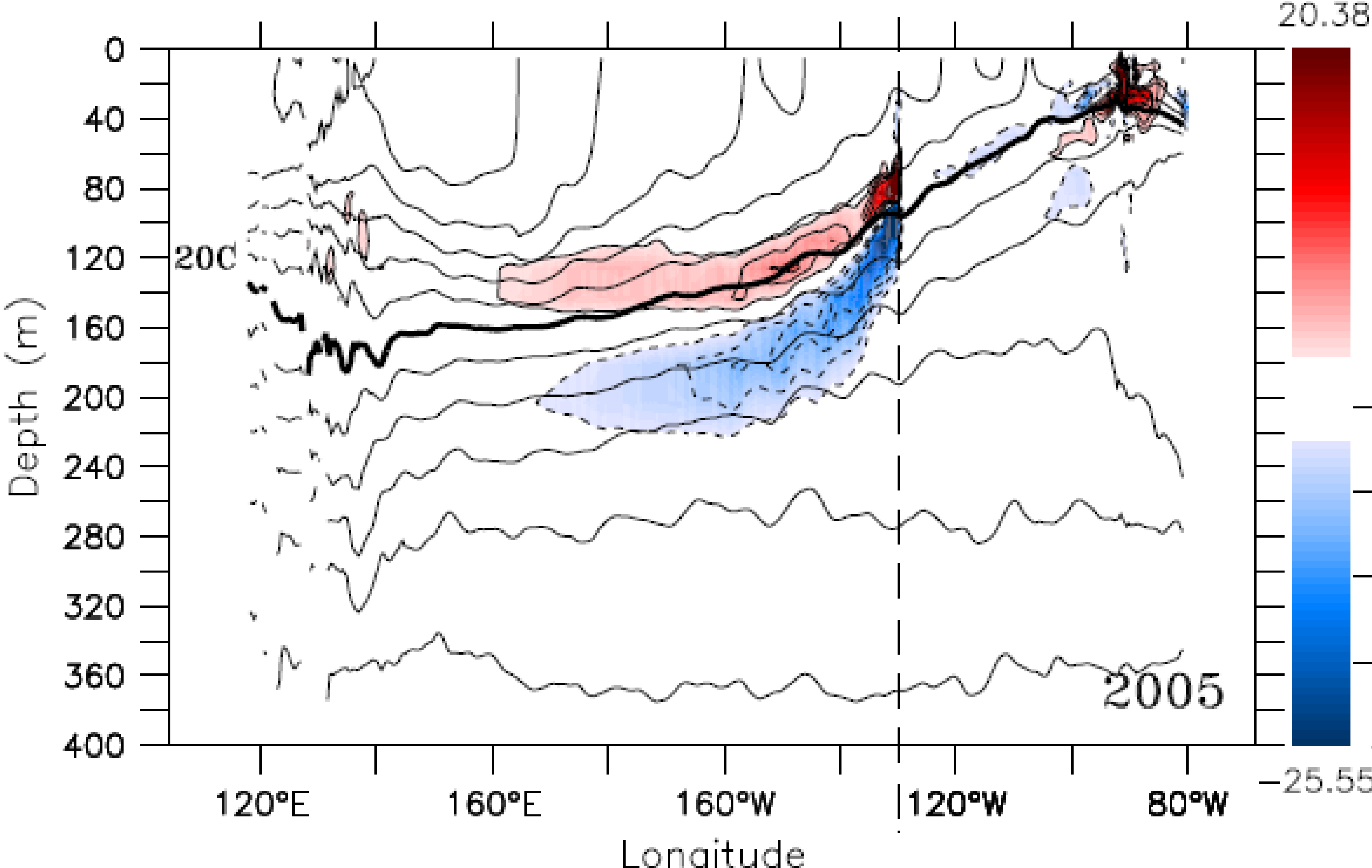
- Tropical Pacific 26°S – 30°N
- 1/3° spatial resolution (also 1/6°)
- 51 zlevels, varying from 5 to 510m
- Topography interp. from ETOPO 2
- Prescribed N, S, W OBCs with OCCA
- T, S, U, V initialization from OCCA
- Forcing: daily NCEP2 state of atmosphere
  (adjoint is forced with ECMWF fluxes)
- Vertical mixing scheme is KPP
  viscAz=1.10^{-4} m^{2}s^{-1}, viscA4=4.10^{11}m^{4}s^{-1}
  diffKzT/S =1.10^{-6} m^{2}s^{-1}, diffK4T/S=2.10^{11}m^{4}s^{-1}
- No relaxation
- Time span is 01-Jan-2004 to 29-Dec-2007



ITF



Sensitivity of temperature at the depth of the 20 degree isotherm at 130W at the end of 2005 to time-independent vertical diffusivity



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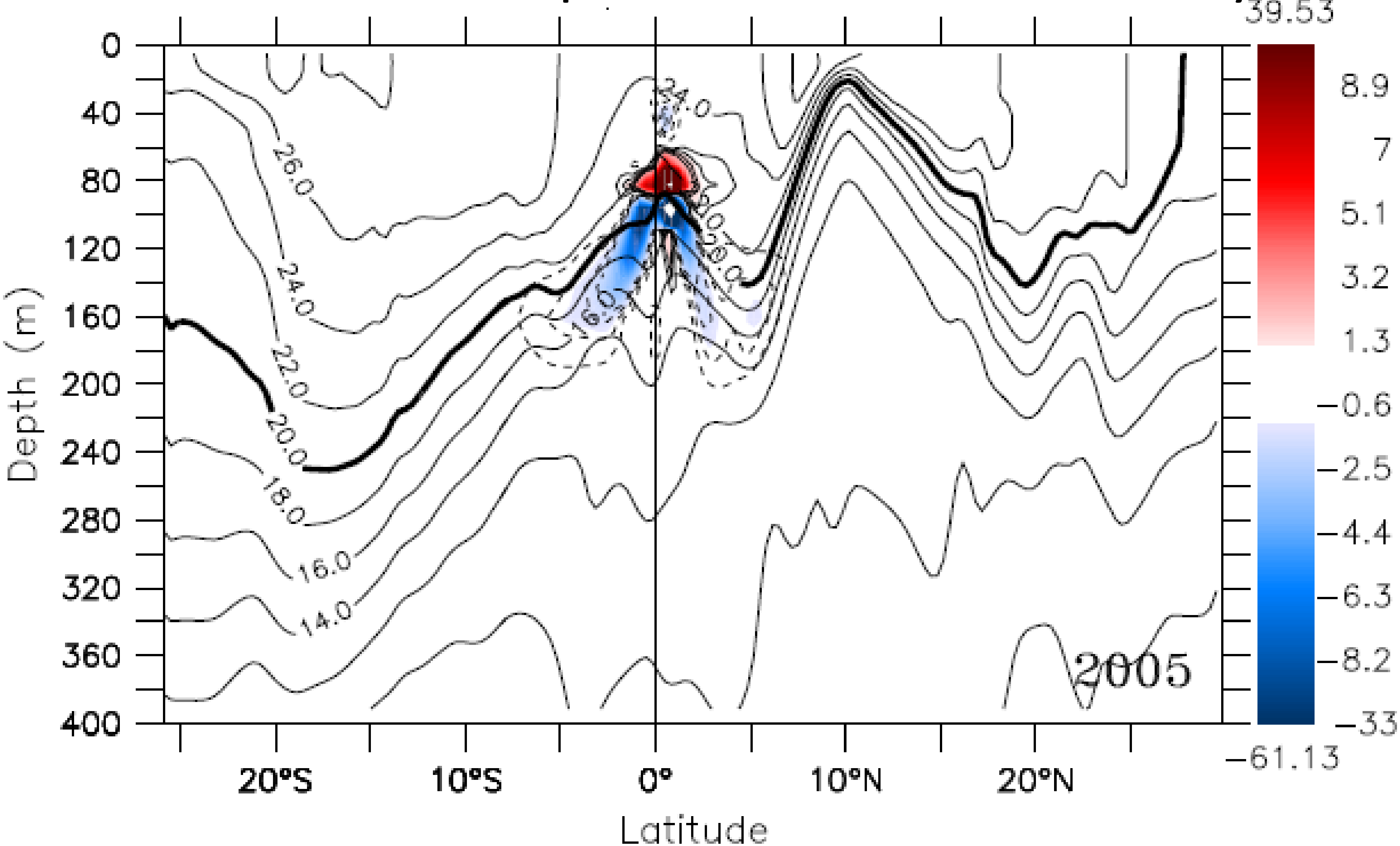
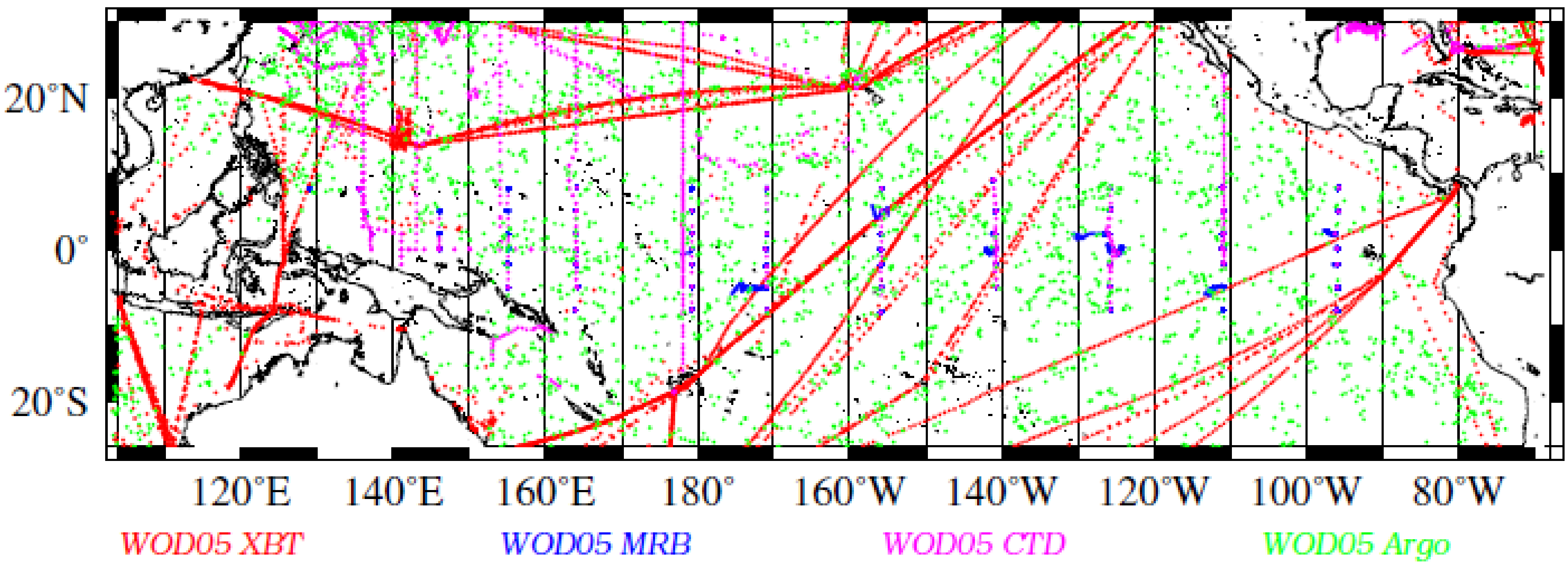
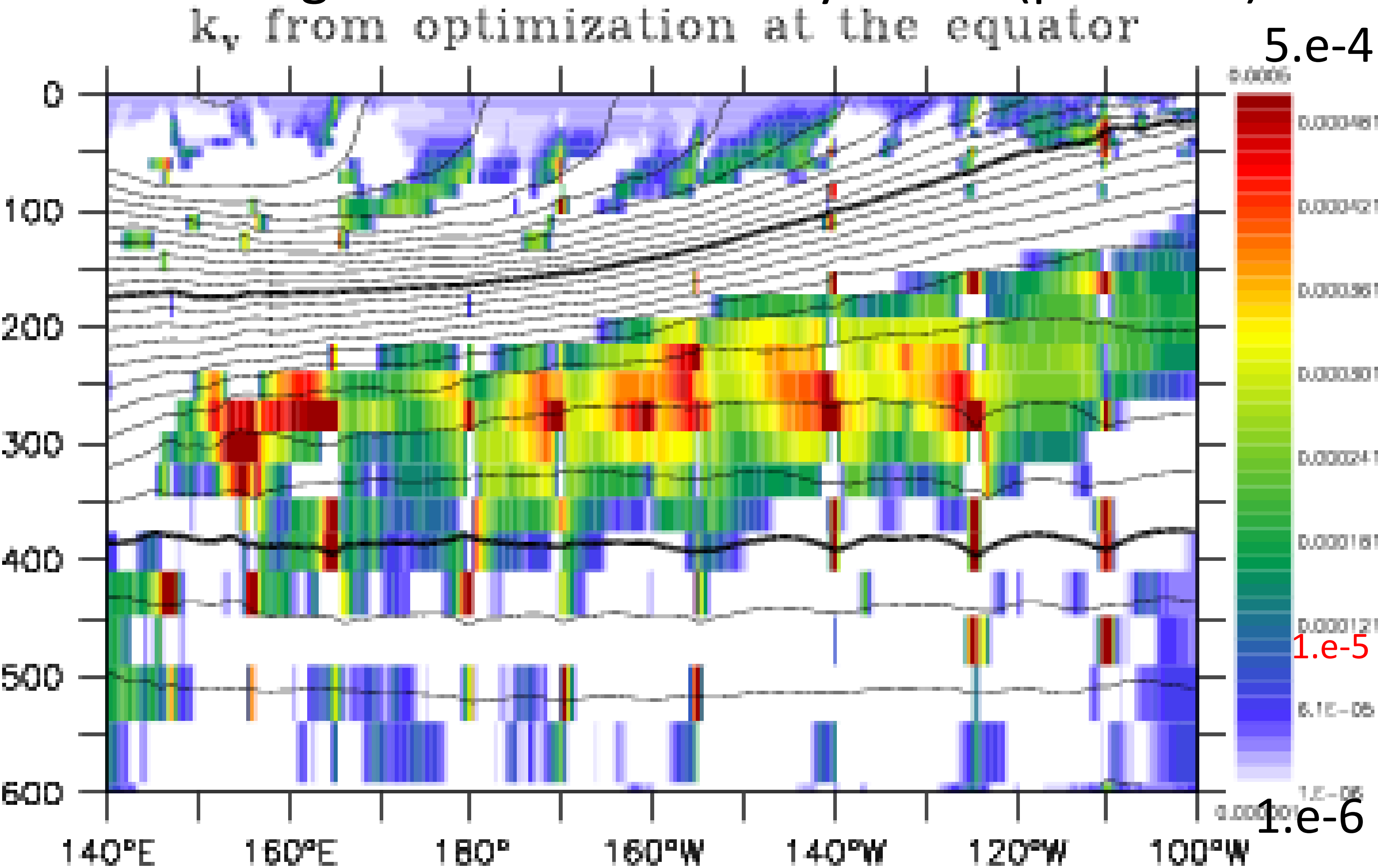


In-situ observations used for 2007 state estimate. Also used altimeter along-track SSH, SST. Adjusted initial conditions, boundary conditions, and atmospheric state (Wind, Temp, Abs Humidity, SW down, precip, etc.), and Kz



Adjusted time-independent Kz
First guess was 1.e-5 everywhere (plus KPP)



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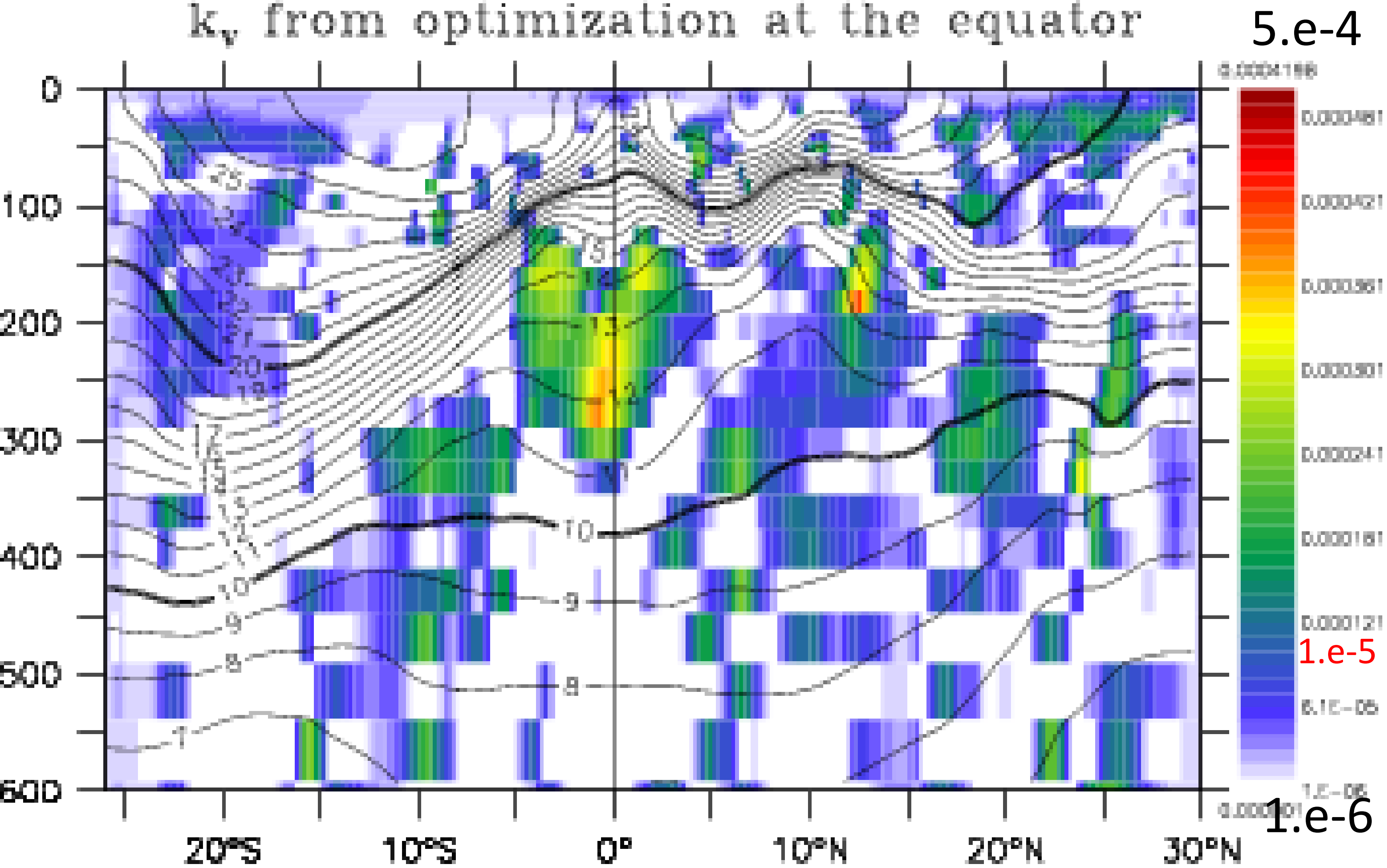


Problems remaining

- Adjoint unlikely for atmosphere, or coupled models
- Time-independent Kz(x,y,z) is not realistic
- Need a prior specifying the places where model error (due to mixing or ???) is large
- Proposal: use modern parameterizations of sub-grid-scale processes and experiment with varying the parameter settings to obtain a better fit to the observations.

Examples of parameters to optimize

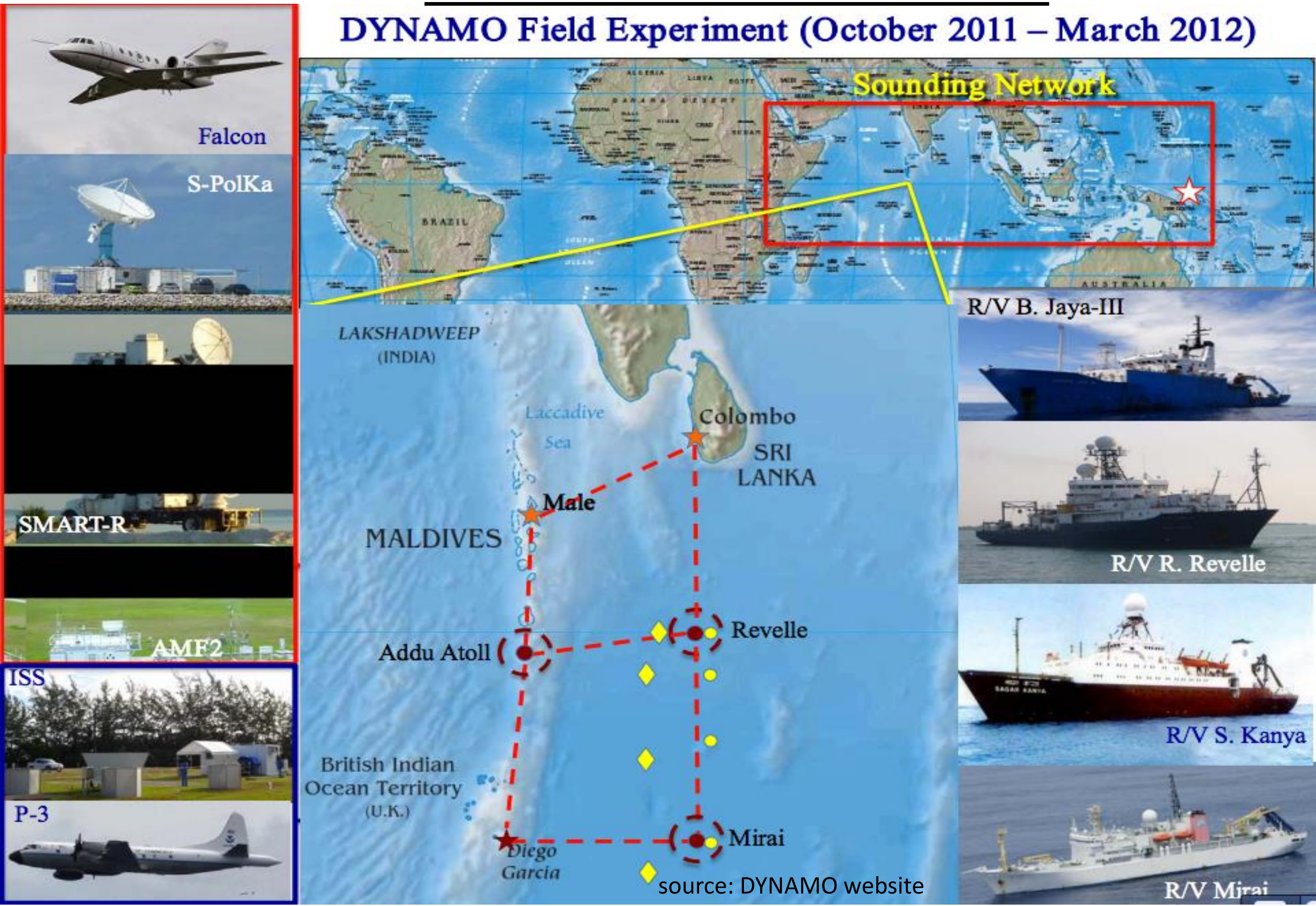
- In ocean: mixing due to tides, internal waves, and convection. Interactions with topography
- In Atmosphere: convection, clouds, other “physics” parameterizations.

Example: MJO project:

- Collaborative Research: Evaluating the Roles of Factors Critical to MJO Simulations Using the NCAR CAM3 with Deterministic and Stochastic Convection Parameterization Closures

- PI : Guang Zhang. Aneesh Subramanian (Postdoc)

Region of Interest



source: DYNAMO website

Motivation

- Extensive observations of Tropical convection , including two MJO events during DYNAMO
- CAM model continues to produce poor MJO simulations due to lack of understanding and parameterization of convection.
- This extensive set of observations, Reanalysis can help guide us in understanding the short-comings of CAM convective parameterization.

Goals

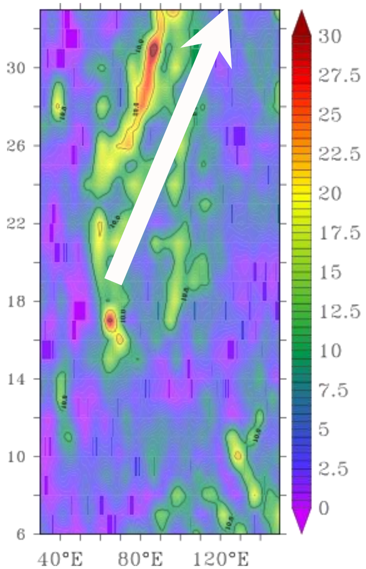
- Improve MJO simulations in CAM
- Also improve tropical convection overall.
- Understand missing physics in CAM from looking at nudging misfits to Reanalysis.
- Convective parameter estimation for the least misfit from Reanalysis/observations
- Focused on 2 highly observed MJO events during Oct-Dec 2011 in the Indian Ocean

Experiment

- CAM RZM model used for hindcasts
- 30 day ensemble hindcasts initialized every 5 days starting Oct 01.
- Initial conditions derived from ECMWF Reanalysis (DYNAMO data assimilated)
- Boundary conditions: Climatological SST vs realtime SST.
- Nudging experiment : lessons learnt

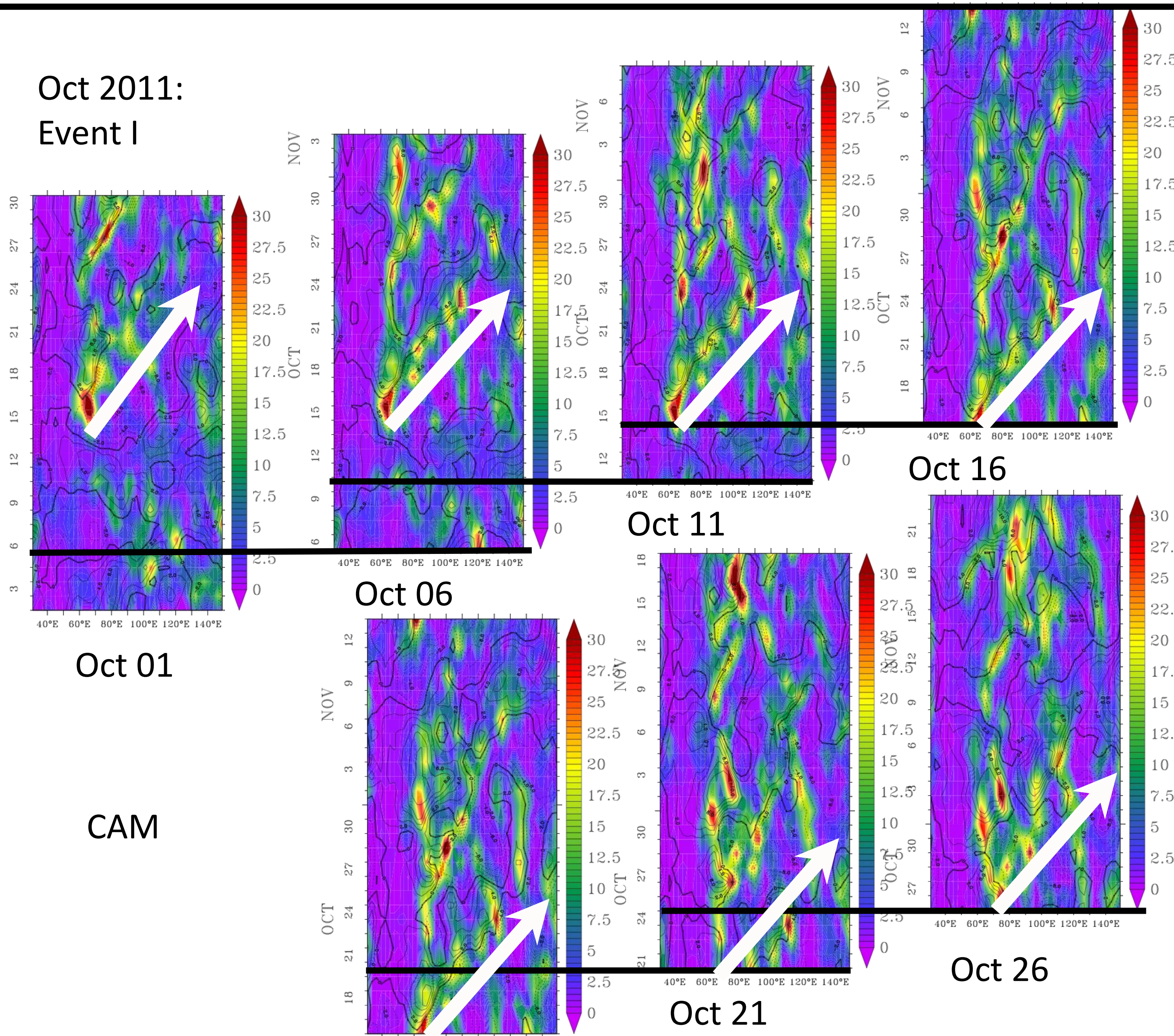
Precip. and U850 Anomaly : Daily SST Forcing

Obs :
TRMM Precip.

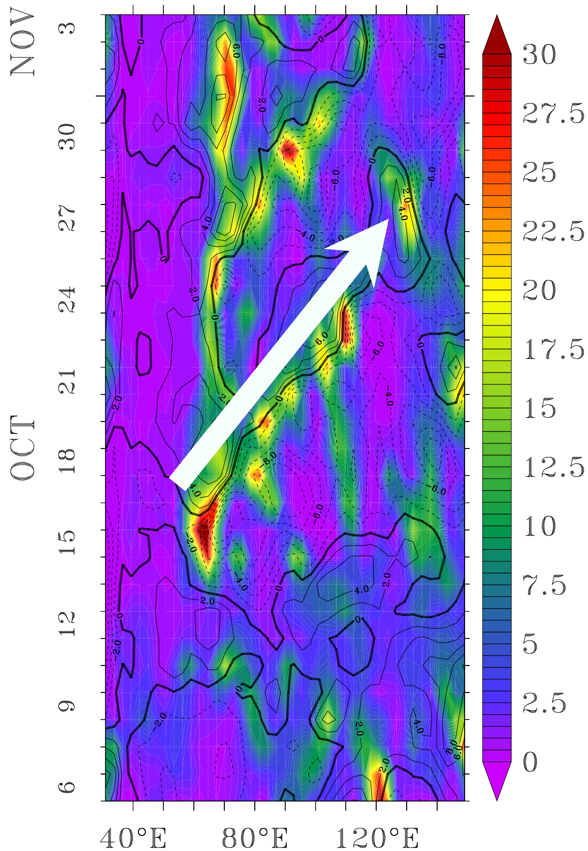


Oct 2011:
Event I

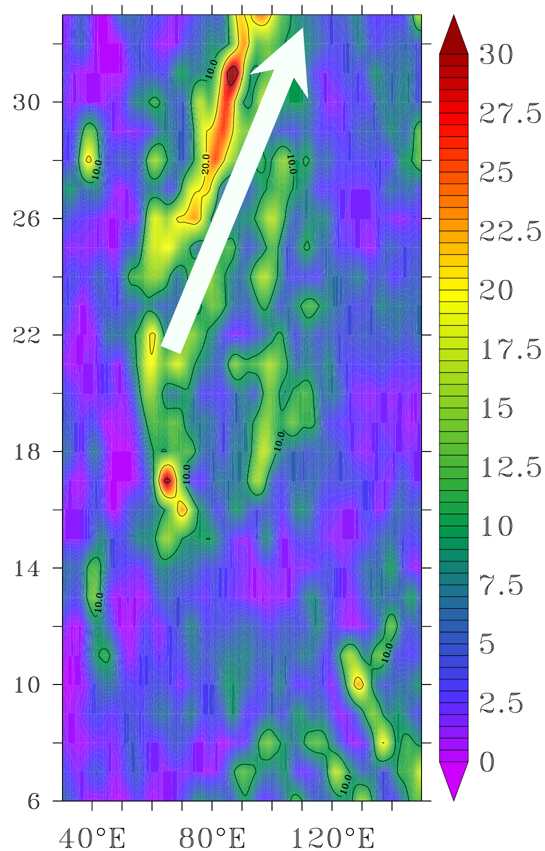
CAM



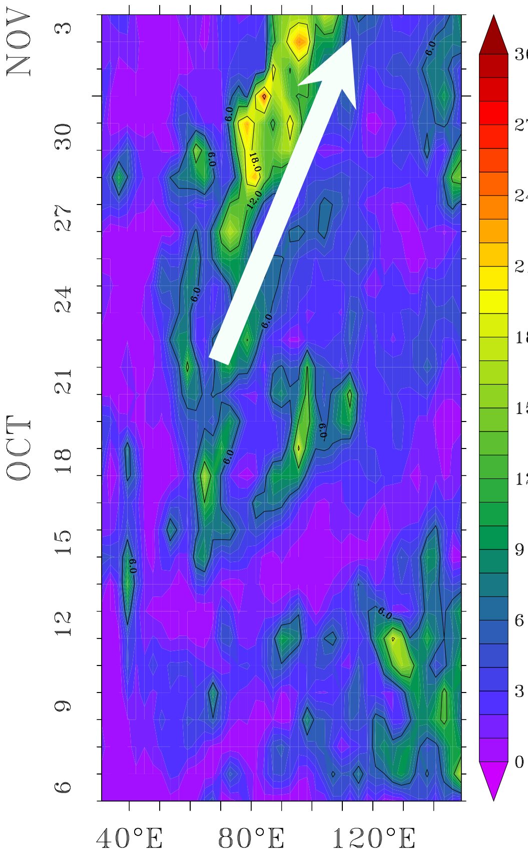
Nudging experiment



CAM -
No Nudging

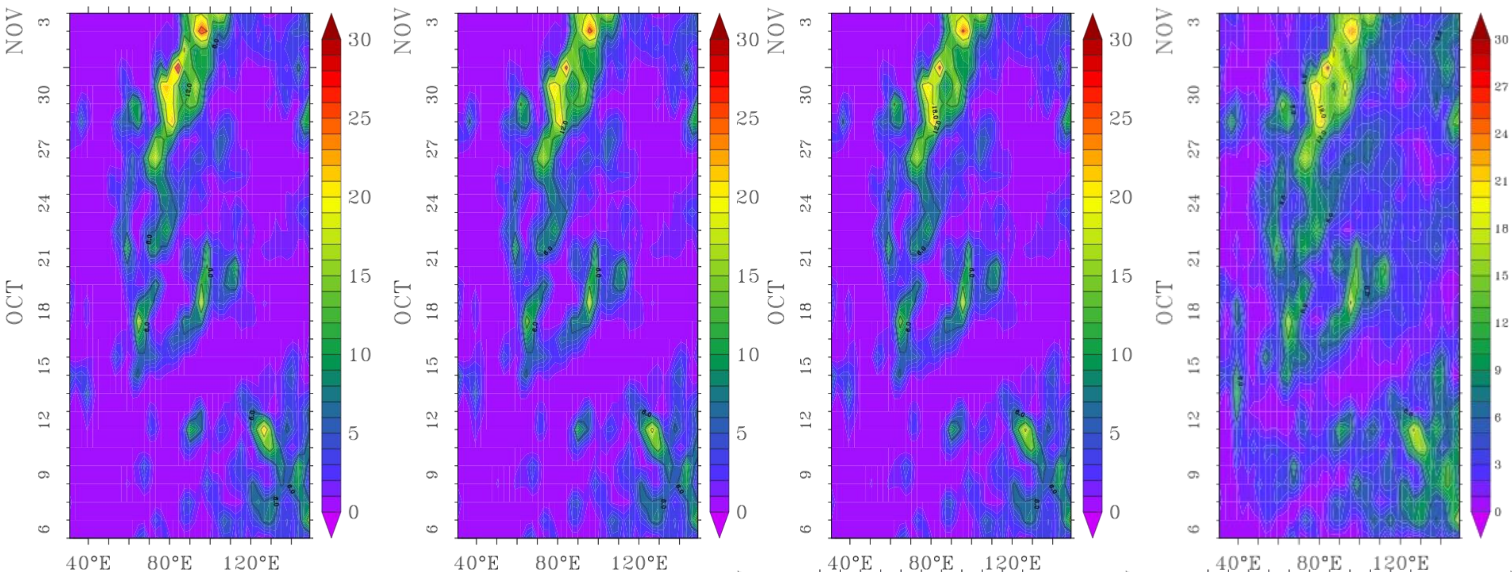


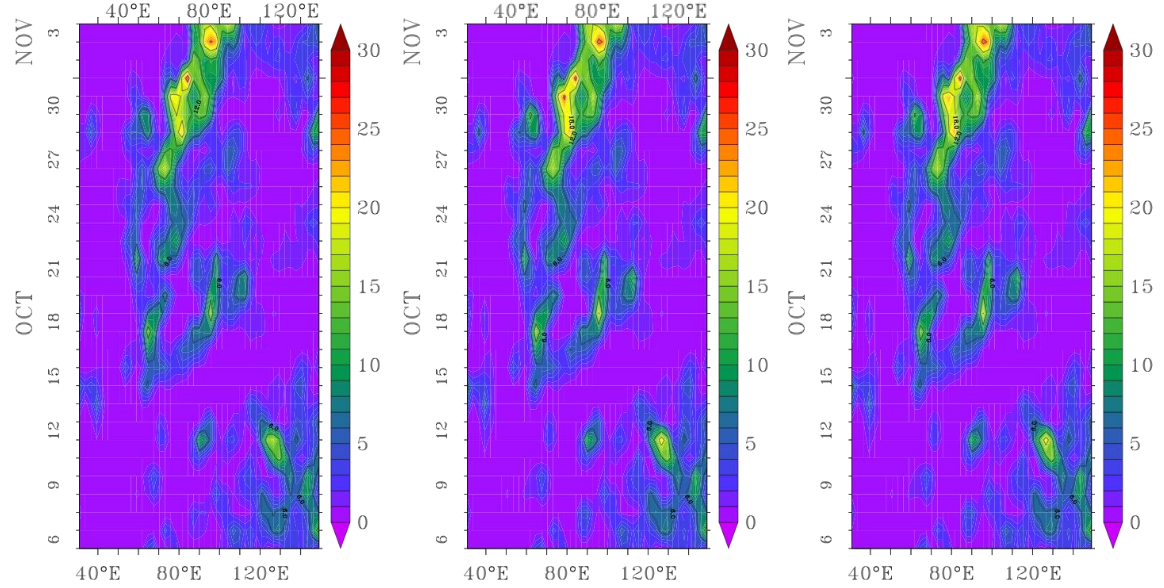
Obs - TRMM
(Precip mm/day)



CAM -
with Nudging

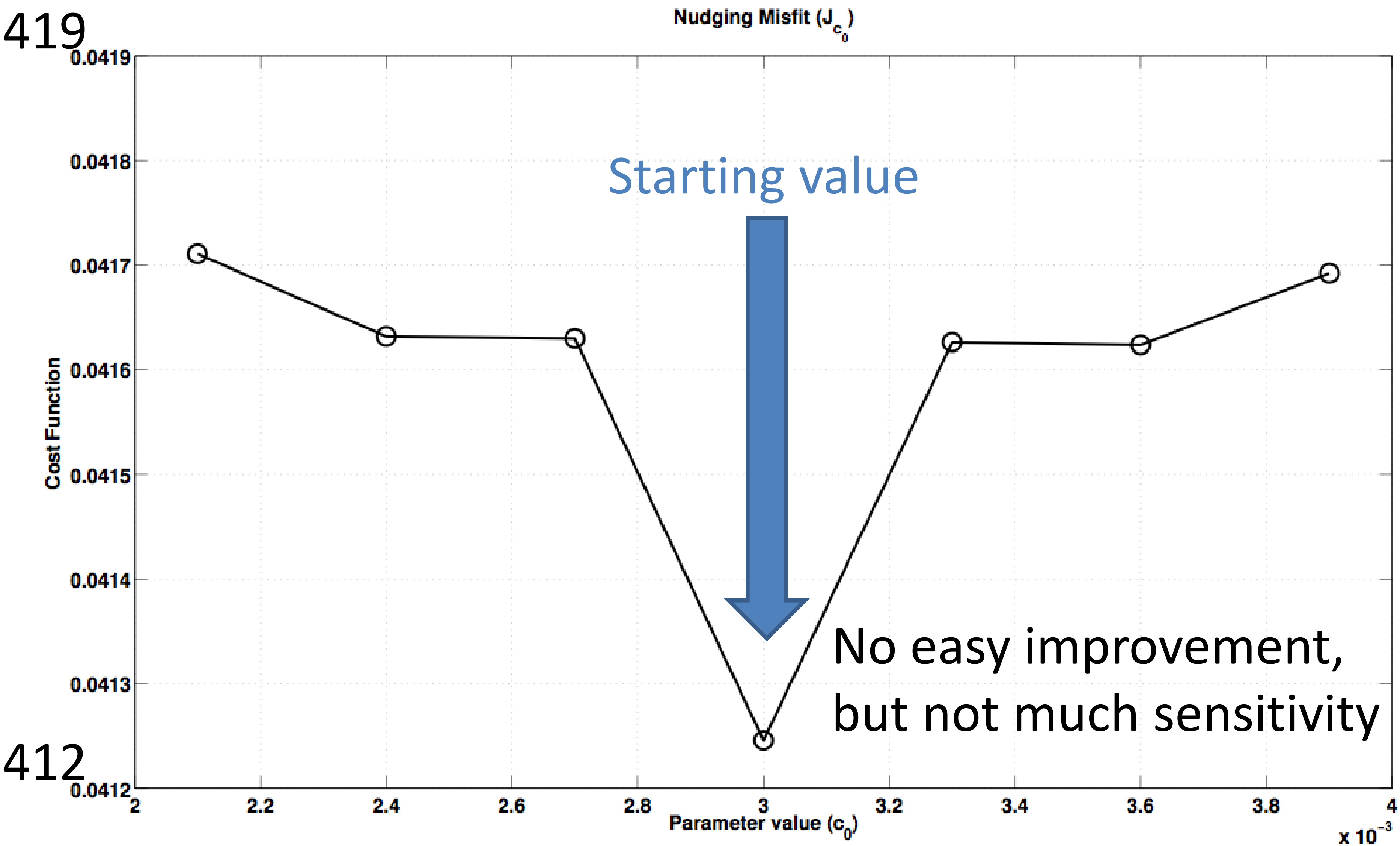
Parameter Estimation:
Rain water conversion coefficient (c0)





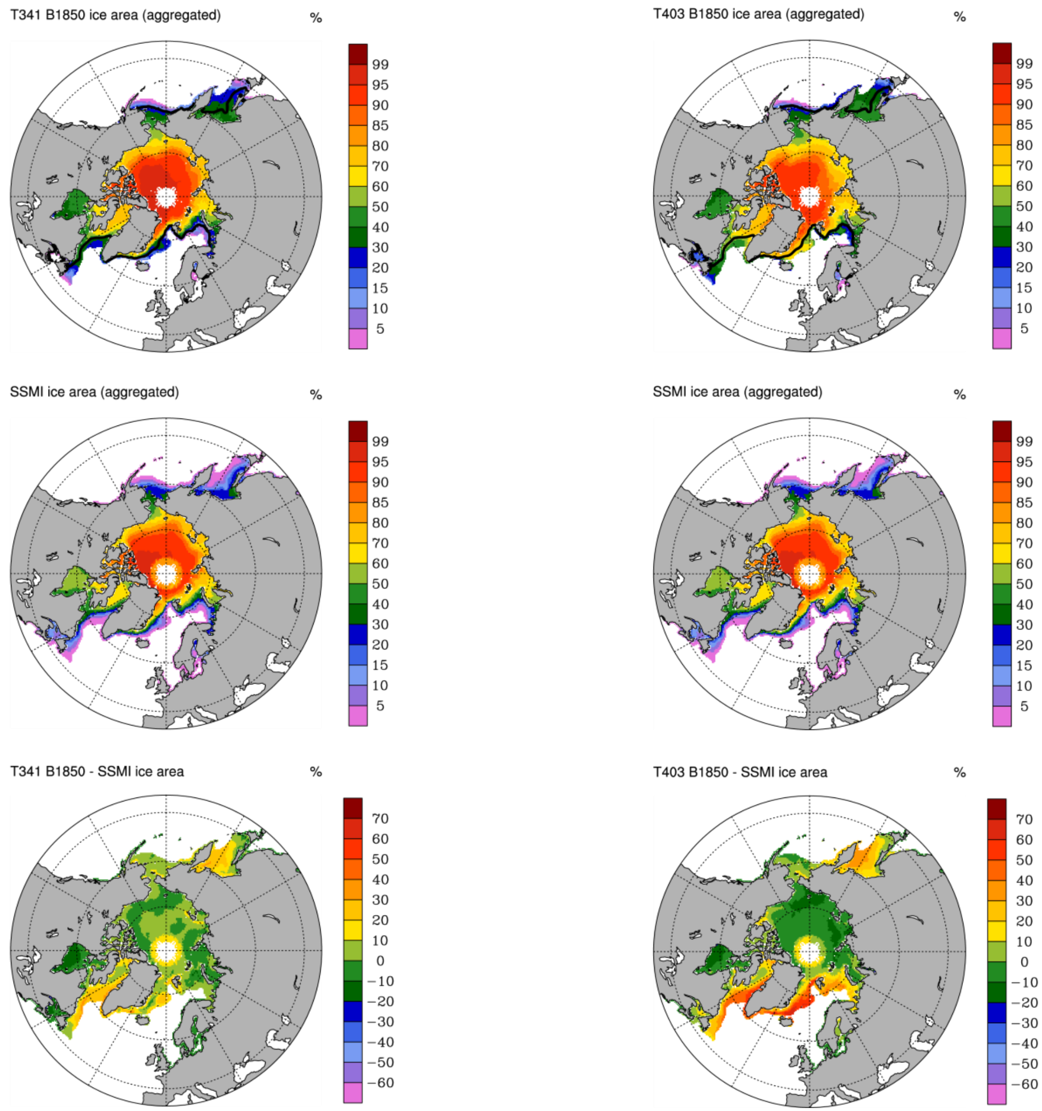
7 Different parameter values of c0

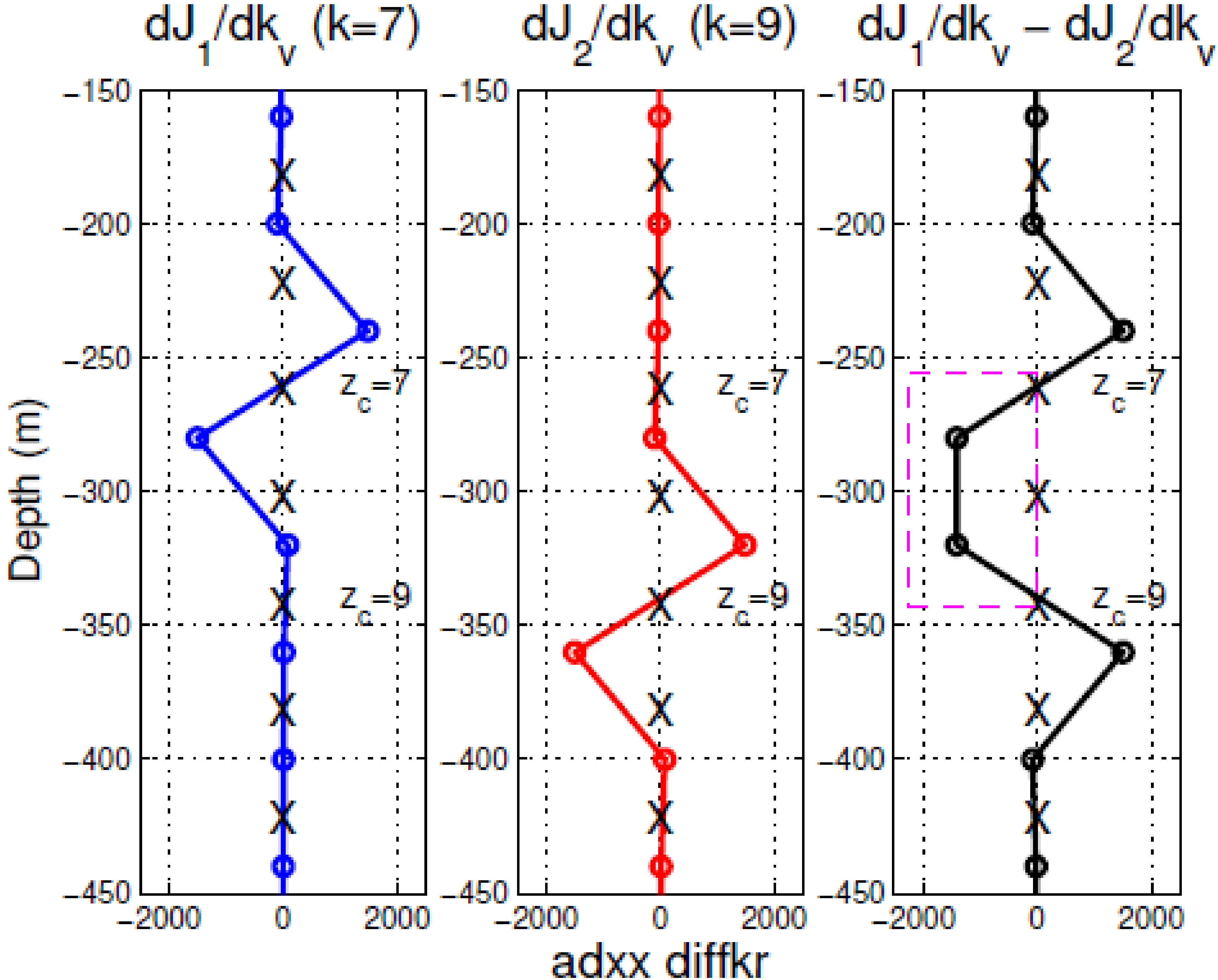
Cost Function: sum of squares of normalized nudging tendency



Thanks for listening!

Annual Ice concentration (%): T341 for years 34-43 (LHS) and ATLAS for years 13-19 (RHS), and SSM/I climatology





dJ1/dkv (k=7)
dJ2/dkv (k=9)
dJ1/dkv − dJ2/dkv
Depth (m)
adxx diffkr
zc=7
zc=9
−150
−200
−250
−300
−350
−400
−450
−2000
0
2000